Ontario

Ministry of Education

Ministry of Colleges and Universities

Hon. Bette Stephenson, M.D., Minister
Harry K. Fisher, Deputy Minister

Energy Ontario

OMTE
371.6
059DE/A2

Lighting for Education

The author acknowledges with thanks comments and information from:

Mr. John Birett, Halton County RCSS; Mr. George Clark, GTE Sylvania Incorporated; Dr. Paul D. Clarke, M.D., Ontario Medical Association; Mr. C. L. Crouch, Illuminating Engineering Research Institute; Professor John Flynn, Pennsylvania State University; Mr. James Groves, Etobicoke School Board; Mr. Walter Jungwirth, Dufferin County School Board; Dr. A.M. Muc, Ph.D., Ontario Ministry of Labour; Mr. John C. Rankin, Ontario Ministry of Education; Dr. Gordon J. Stopps, M.B., University of Toronto; Mr. Murray Young, Dufferin County School Board; and the Illuminating Engineering Society of North America.

Contents

1. Introduction 3

2. Creating a Good Visual Environment: Basic Considerations 5

Illuminance 5
- The effect on visual performance
- Illuminance recommendations
- The advantages of providing more than one illuminance
- Equivalent Sphere Illumination (ESI)
- Lighting for visually impaired students

Glare 8

Brightness Balance 10

Colour 11
- Colour appearance, colour rendering, and the choice of colours used in decorating
- Colour rendering and the choice of lamps for school activities

3. Lamps and Ballasts 13

Lamps 13
- Incandescent lamps
- Fluorescent lamps
- Dummy lamps
- High intensity discharge (HID) lamps:
  - Mercury lamps
  - Metal halide lamps
  - High pressure sodium lamps
  - Low pressure sodium lamps
- Operating characteristics of HID lamps

Ballasts 16

4. Windows and Daylight 19

The Effectiveness of Windows 19

Screening Devices for Controlling Glare and Sunlight 19

Aspects of Daylighting Design 20

5. Some Effects of Lighting 21

Lighting and Health 21
- Ultraviolet radiation and health
- HID lamps in schools
- Lamp colour rendering and the choice of illuminance
- Loss of muscle strength under various light sources
- Lamp flicker
- Fluorescent lighting and hyperactive children
- Student tiredness
- The windowless school

Special Lighting Requirements 23
- Lighting for areas with visual display units (VDUs)
- Lighting for plant growth

6. Switching and Energy Management in Lighting Systems 25

Manual Switching 25

Time Controls 25

Photoelectric Controls 25
- On-off photoelectric control
- Top-up photoelectric control

Occupancy Detector Control 26

Monitoring Lighting Use: The Elapsed-time Meter 26

7. Making the Most of Your Lighting System: Basic Considerations 27
- Procedures requiring no capital investment
- Procedures with short pay-back period
- Procedures with long pay-back period

8. Exterior Lighting 29

9. Lighting in the Year 2000 31

Bibliography 33

Glossary 34

Appendix 1: Principal Lamp Types Used 35

Appendix 2: The Effects of Ultraviolet Radiation 39

Mohawk College, Wentworth Campus, Hamilton

Algonquin College, Woodruffe Campus, Ottawa

Murray & Murray, Architects

1. Introduction

The general appearance of a classroom – the way the classroom looks and the quality of the lighting – has an immediate and marked impact on both teachers and students. It affects their enjoyment of the classroom: one that is gloomy and monotonous, and in which neither teachers nor students look their best, will not be a pleasant place in which to work. It also affects the students' ability to learn. School work makes exceptional demands on the vision of the students. If the visual environment is such that they cannot see well, then they will not learn well.

When we say that we like the lighting in a particular classroom, we are usually referring to more than just the lamps and luminaires used to produce the effect. What we are really talking about is the total result – the visual environment.

The visual environment is the most sophisticated and best documented aspect of environmental design. It involves windows and the amount of daylight they let in; the quality of the electric lighting system; the colours and finishes used on walls, ceilings, and other surfaces; and the design and layout of the furniture – to name some of the major considerations. It also involves consideration of energy costs and consumption.

Improvements in lighting technology since the turn of the century have greatly increased our ability to control the visual environment. In the early 1900s, there was no electric lighting in schools, and classrooms had to have high ceilings and tall windows to let in sufficient daylight. The window location determined the front of each room since the students were seated so that the light was over their left shoulders. They were all assumed to be right-handed. What artificial lighting there was came from coal-oil or gas lamps.

A major development in school lighting occurred just after the First World War. This was the introduction for general use of the incandescent tungsten filament lamp – the sort of lamp found in every home today. To begin with, this form of electric lighting merely supplemented daylight: it was not used to replace daylight to any great extent. But as these lamps became more efficient and electric energy became cheaper, daylight was considered less as the source of light for classrooms.

The tubular fluorescent lamp was introduced after the Second World War and brought about a radical change in the thinking on classroom lighting. With this high-efficiency lamp (it is now three to four times as efficient as the incandescent lamp), many of the previous restrictions on classroom lighting were overcome. It now became cheap enough to make it possible to have virtually as much light as we wanted whenever we wanted it. Consequently, the fluorescent lamp was adopted as the principal means of classroom lighting. The classroom was sometimes provided with large windows, sometimes with small windows, and occasionally with no windows at all. Even when the classroom had large windows, daylight was usually considered as a bonus additional to the electric light.

PHOTO: KARL SOMMERER

Cambrian College, Barrydowne Campus, Sudbury
Townend Stefura Baleshta & Phister, Architects

PHOTO: KARL SOMMERER

Lighting in universities followed a similar pattern of development. Many of the universities with older buildings were slow to adopt the fluorescent lamp as a light source for aesthetic reasons. Their attitude changed, however, as new buildings were constructed incorporating advanced forms of lighting systems. There was, as might be expected, a marked contrast in lighting conditions between the old and new buildings. As a result, there has been a continuing upgrading of the visual environment throughout the post-secondary system.

Colleges of applied arts and technology, a comparatively recent development on the education scene, did not have to make this transition. They are almost all served by new or extensively renovated buildings, and their standards of illumination reflect the design philosophy of the 1960s and 1970s.

The last quarter of the twentieth century presents a new challenge. Advances in lighting technology must now be reconciled with the increasingly vital considerations of energy costs and conservation. Although lighting of all kinds consumes only about 5 per cent of the total national consumption of energy, it is a particularly conspicuous user of energy. Inevitably, as the cost of energy rises, there will be pressure applied to reduce the amount of energy consumed by lighting systems.

The solution to this problem is by no means a simple one. The "energy crisis" has in fact focused attention on a number of possible energy-saving approaches. There is increased interest in the lighting levels – the illuminances – recommended for schools; in the use of daylight; in the use of high intensity discharge (HID) lamps; in the design of more effective luminaires; and in switching procedures. These considerations, together with others such as colour and colour rendering, will be discussed in these pages.

Lighting design requires skill and experience to weigh one design element against its effect on the others. Designers must be constantly aware of the interaction between the elements. And they must appreciate that tables of figures and codified procedures are possibly not as reliable a guide as was once thought – it is experience that must count now.

This booklet sets out to be not so much a rigid guide or checklist but rather to consider some of the qualities and quantities that must be juggled to produce good lighting for education.

Georgian College, Barrie Campus, Barrie
Page & Steele – Salter & Allison, Architects

2. Creating a Good Visual Environment: Basic Considerations

In order to create a good visual environment, we must be concerned with:

1. producing enough light;
There must be adequate illuminance to enable us to do what we want to do quickly and accurately.

2. limiting glare and extreme contrasts in brightness;
Both these factors may not only cause visual discomfort but actually reduce our ability to see.

3. producing the right kind of light;
The major factors here are colour and colour rendering. Colour rendering is concerned with the way coloured objects look under different types of light sources. If colours used in the room are such that they are distorted by the light source, the general effect will be displeasing.

A further overall concern is of course the need to keep down costs and conserve energy.

Illuminance

The effect on visual performance
How much light is required to see what we need to see quickly and accurately? (For example, we might be reading a book or vernier, inspecting a weld, or making a drawing.) Or, to put it in the usual jargon, what illuminance is required to perform a given visual task?

Visual performance depends on many human and physical factors. The human factors include the basic variability from one person to another, the effects of age and fatigue, and the degree of training or experience a person has in what he or she is doing. A skilled person needs less light than one who is unskilled, all other things being equal.

The physical factors affecting visual performance are concerned with what we wish to see – that is, the visual task – and its background or the visual field in which it lies. These factors include the nature of the task and its inherent difficulty.

Visual performance is improved if:

- there is good contrast between the task and its background
- there are no reflections – called veiling reflections – from the task
- there is no severe glare from the luminaires or other light sources (including the sun)
- there is an increase in the illuminance provided

Illuminance recommendations
A person with normal sight benefits from increased illuminance: he or she sees faster and more accurately. Thus any illuminance recommended for a particular visual task is almost always a compromise between the benefits from increased illuminance on the one hand and the amount (and cost) of energy to provide that illuminance on the other. Such a compromise is not by any means easy, and there is a further, complicating factor: in everyday situations, as opposed to laboratory situations, it is practically impossible to determine the effect on visual performance resulting from varying the illuminance within quite wide tolerances around its prescribed value (i.e., the recommended illuminance that applies at the time).

The Illuminating Engineering Society of North America (IES) publishes recommended illuminances for different visual tasks. These recommendations have been generally accepted in Canada. The IES committees responsible for making the recommendations are made up of lighting specialists from both Canada and the USA.

Illuminance recommendations are not immutable. The IES is currently (1981) in the process of issuing new recommendations which are to supersede those that have been in use for the past twenty years.

Continuing research has shown that the fundamental system used to establish illuminance recommendations cannot be completely and scientifically established. A new system based on research is ten years away. Consequently, an alternative approach has been adopted by the IES. It is based not on research but on consensus – a majority agreement of individuals knowledgeable in lighting research and application. That agreement was reached after a review of

Table 1 / Recommended Illuminances

Classroom	
Kindergarten[1]	350 lux
General classrooms, seminar rooms	500 lux
Visually impaired students	1500 lux
Large group instruction areas (including lecture theatres)[2]	250 lux
Auditorium	
Assemblies only[2]	250 lux
When used for study or examinations	500 lux
Cafeteria	
General	250 lux
Servery	350 lux
Kitchen	500 lux
When used for study or examinations	500 lux
Drafting	
General	500 lux
On boards[3]	1000 lux
Graphic arts	
General	500 lux
On boards[3]	1000 lux
Gymnasium (Gymnatorium and Cafetorium)	
General	250 lux
When used for study or examinations	500 lux
Laboratories	
General	500 lux
Demonstrators' desks	750 lux
Library	
Stacks (with little local reading)	250 lux
Reading, note taking, cataloguing	500 lux
Seminar rooms	500 lux
Offices	500 lux
Music room	500 lux
Sewing[3]	500 lux
Shops[3]	500 lux
Typing	500 lux
Washrooms and locker areas	250 lux
Corridors	
With lockers	250 lux
Without lockers[3]	100 lux
Mechanical and service areas	250 lux
Storage areas	100 lux

Notes:

1. The illuminance of 350 lux has been selected for the kindergarten since the visual tasks are not severe.

2. It should be possible by simple switching to vary the illuminance by 50 per cent either up or down to accommodate note taking or audio-visual presentations. Total control by areas is desirable.

3. Local lighting may be used to supplement the general lighting where fine work is to be carried out or feature displays are located. Supplementary lighting is frequently provided for chalkboards. Since study carrels cut off light from the overhead general lighting system, a local lighting luminaire in each carrel is frequently desirable.

available vision research and of lighting practices in other countries. The consensus approach of the IES has been used as the basis for the illuminance recommendations in these guidelines. (See Table 1.)

The previous method of allocating one illuminance as the only one appropriate for a particular visual task has been dropped. Instead, visual tasks are grouped into a series of categories with a range of three illuminances applicable to each category. The appropriate illuminance is selected from the range of three by means of a system of weighting factors. These factors recognize that working speed and accuracy are improved with more light; that more light is needed if contrast in the visual field is poor; and that more light is needed as one gets older. This last point is important if classrooms are to be used by adults as well as by young students.

These weighting factors have been considered in selecting the illuminances for school spaces shown in Table 1.

The advantages of providing more than one illuminance

The choice of illuminances to be used has a direct effect on the electric power (i.e., the watts) drawn by the lighting system and on the energy consumed. The choice is thus of great importance in these days of energy management and high energy costs. If an illuminance of, let us say, 300 lux can be used instead of 500 lux, then there is straightaway a potential reduction of one-third in the amount and cost of the energy consumed.

The choice of illuminance will depend (among other things) upon the visual task. The more difficult the task, the greater the illuminance required.

It is not always possible, however, to designate classroom use at the time the lighting systems are designed, and thus to design each system to suit a particular use. Accordingly, the practice has been to provide a general lighting system with one fairly high illuminance throughout the general classrooms and spaces. This takes care of most difficult visual tasks such as reading a paperback book or pencil handwriting. But the fact is that a kindergarten class, with no difficult visual tasks, can operate perfectly well with a lower illuminance. With such a general lighting system, therefore, it is inevitable that some classrooms will be provided with a higher illuminance than they need. As a result, more energy will be consumed than is necessary.

A way around this problem is to consider a lighting system capable of providing two levels of illuminance. This can usually be achieved by simple switching, by the use of special ballasts which provide two light outputs from fluorescent lamps, or by the use of lamp-dimming circuits. These techniques are discussed in sections 3 and 6.

Equivalent Sphere Illumination (ESI)

Providing the recommended illuminance for a particular visual task is no guarantee that the task will be seen well. This may seem an astonishing statement to make – it raises the question of why there should be recommended illuminances at all. But we have all noticed the effect of a patch of sunlight on a chalkboard: the reflected glare makes it impossible to read the writing on the board even though the light level is more than enough.

A similar, but much less obvious, phenomenon occurs where there is reflection of a large luminous area in the print or on the surface of a page, even where the text is printed on dull or matt paper. The effect – very possibly undetectable by the naked eye – is as though a luminous veil were superimposed over the visual task. Hence the name "veiling reflections". Veiling reflections create the most insidious problems on semi-glossy pages with print or pencil writing. They reduce the contrast between the print or writing and the page, making reading more difficult.

How well one sees a visual task depends on more than just providing the right illuminance. It depends on contrast. This, in turn, depends upon the reflection characteristics of the visual task, the locations of the luminaires and the observer with respect to the visual task, and the distribution of light from the luminaires.

The above considerations have led to the concept of Equivalent Sphere Illumination (ESI). ESI is a method of specifying illuminance in such a way that it takes contrast into account. Since, as we have seen, contrast affects visibility, the method has the potential of being a more effective way of indicating how well a lighting system enables one to see a particular visual task than a method in which only the illuminance (measured in lux) is specified.

In recent years ESI has been used to specify the illuminance for a number of visual tasks. This booklet, however, does not recommend this practice. The main reason for this is that insufficient experience has been obtained with ESI to permit the inclusion of ESI values in the consensus approach to illuminance recommendations.

Further, in order to obtain the maximum ESI on a visual task, that task must be carefully located with respect to the luminaires in the lighting system and to the windows. In many classrooms the working positions are changed frequently as the work and the composition of the class are changed. So there is no guarantee that the resultant ESI on the visual task is at its desired level.

Finally, ESI requires a computer program for its design calculations. It also requires a very special photometer and a second (but smaller) computer program to convert the photometric measurements into ESI.

Lighting for visually impaired students
About one-half of school-age children who are legally blind, as registered with the American Printing House for the Blind, have useful vision at the near point and are able to use printed material as their means of learning. Thus many a legally blind child will become a more effective and efficient reader of that material if attention is paid to the visual environment in which he or she works.

It is generally accepted that most visually impaired students benefit from increased illuminances, although exceptions to this are recognized – for example, people with achromatopsia and cataracts. An illuminance of 1500 lux has been recommended by the IES for classrooms for the visually impaired, although higher illuminances have been used. This illuminance – about three times that adopted for many general classrooms – might be from a general overhead lighting system or from a combination of general lighting plus supplementary lighting on the work.

Some visually impaired students read with their eyes close to the printed page. The lighting system for these students must be designed so that the light is not severely obstructed by the student's head: the light must fall on the page.

SUMMARY

- Design the lighting system to maintain the appropriate illuminances on the visual tasks. Refer to the recommended illuminances shown in Table 1.
- Try to ensure that visual tasks of good contrast are used; if this is not possible, locate those tasks so that one does not see reflections off them.
- Consider a lighting system capable of providing more than one level of illuminance if the space is to be used by adults as well as children.
- The use of Equivalent Sphere Illumination (ESI) is not recommended.
- A higher illuminance than normal is recommended for students with impaired sight. The lighting design must also take into account the possibility that these students may obstruct the light by sitting with their eyes close to the visual task.

Glare

Glare occurs when the luminance – the "brightness" – of some parts of the field of view is substantially greater than that in other parts.

Glare can take two forms. First, it can reduce the ability to see. This is known as *disability glare.* It commonly occurs in buildings when a bright light is reflected off a surface. For example, the sun shining on a chalkboard can cause disability glare – from certain parts of the classroom it may be impossible to see anything that is written on the board. Teachers may be unaware of this problem. They place themselves in a position where they can see well, little realizing the visual difficulties the students are experiencing.

Secondly, it can cause discomfort. *Discomfort glare* can be present without reducing the ability to see. This is particularly true in very bright surroundings which result from a liberal display of bright luminaires. Little or no disability may be caused, but the discomfort may be marked. Discomfort glare can also be caused by daylighting if the windows provide a clear view of the sky.

Discomfort glare is a function of the luminance and the size of the luminaire, and of the number of luminaires in the field of view. The brighter the luminaire, or the bigger the luminaire, or the greater the number of luminaires seen, the greater the discomfort glare that will be caused. The influence of the luminance of the luminaire is particularly significant. If the luminance is doubled, but all other factors are held constant, the glare effect will be more than trebled.

The colour of the surroundings is also a contributing factor. Discomfort glare can be reduced if light colours are used. A luminaire that can cause intense discomfort in a space with dark walls may be quite innocuous if the walls are painted a light colour. This is a simple and effective way of reducing discomfort glare, but there is one possible drawback: Care must be taken to ensure that the walls themselves do not become too bright and thus cause discomfort glare. There have, for instance, been complaints from typing students who have had to sit facing a bright wall.

Finally, discomfort glare is influenced by the positions of the luminaires relative to the line of sight. A luminaire right in the line of sight can cause considerable discomfort glare. A luminaire out of the line of sight will, of course, cause no discomfort glare.

Glare can be caused by any form of lighting, including indirect lighting. Both direct and indirect HID lighting systems, in particular, should be studied for their potential to cause glare.

Indirect lighting has a soft, diffuse quality. The lamp is completely screened from view, and all the light is directed onto the ceiling which reflects it down to the desks. Nevertheless, indirect lighting can cause glare. Unless the luminaires are well chosen and correctly spaced apart, very bright spots may appear on the ceiling directly above the lamp – particularly if HID lamps are used. These bright spots may cause glare.

A number of methods have been developed to specify the discomfort glare characteristics of a lighting system. In North America the Visual Comfort Probability (VCP) method is used.

Suppose that a uniform general lighting system is designed to give a particular illuminance using a particular luminaire in a room with particular decoration. VCP data provided for that luminaire will show the percentage of people who, seated in the most undesirable location (i.e., with the most glare), would find the lighting system acceptable.

When first designed, the system might show a VCP of only 50 per cent. This is probably too low: a figure of 70 per cent is frequently used, although the adoption of this value is arbitrary. So the system would have to be redesigned, using, possibly, luminaires of lower luminance, in order to increase the VCP to 70 per cent.

The limitations of VCP are that it applies only to (1) general overhead lighting systems illuminating horizontal surfaces, such as desk tops; and (2) the location in the room with the worst discomfort glare effect. Thus, if the work surface is not horizontal, if the layout of the working positions changes from time to time, or if the uniform general lighting system is not used, VCP has little or no value.

There is, however, a simple way of appraising an existing lighting system for discomfort glare. Select typical locations in the room and shade the eyes with the hand held horizontally. If, as a result, the lighting suddenly becomes more comfortable, then the lighting system is likely to be too glaring. Obviously this method cannot determine with any precision by how much the discomfort glare should be reduced, but it is still a valid test and one that is not subject to the limitations of VCP that have been mentioned.

SUMMARY

- Glare can take two forms – *disability glare* and *discomfort glare*.
- Disability glare reduces the ability to see. It commonly occurs when a bright light is reflected off a surface. The sun's rays, for example, can easily cause disability glare.
- Discomfort glare is a function of the luminance and size of the luminaires, and of the number of luminaires in the field of view.
- Glare can be caused by any form of lighting, including, perhaps surprisingly, indirect lighting. Study both direct and indirect HID lighting systems, in particular, for their potential to cause glare.
- Visual Comfort Probability (VCP) is a method of specifying the discomfort glare characteristics of a lighting system used in North America. It has little or no value if the work surface is not horizontal, if the layout of the working positions changes frequently, or if a uniform general overhead lighting system is not used.
- Study a lighting system by shielding the eyes with the hand. If, as a result, the lighting suddenly becomes more comfortable, then the system is likely to be too glaring.

Brightness Balance

The appropriate illuminance alone is no guarantee of a classroom that is a cheerful and pleasant place in which to learn. The colour and brightness of the principal surfaces – ceiling, walls, floor, and furniture – also play their part in creating the classroom environment. Brightness, in particular, determines how comfortable a classroom is visually. A classroom with dark walls and dark furniture, for example, will be gloomy whatever the illuminance.

A proper balance of brightness levels must be maintained. If there is a substantial difference in brightness between the visual task and the area immediately surrounding it, or between large adjacent areas in the students' field of view, then they may well experience visual discomfort.

The luminance of the principal surfaces is determined by the lighting system and by what are called the *reflectances* of those surfaces. Recommended reflectances for the principal surfaces are shown in Table 2. Their use will ensure that there is an appropriate balance of brightness levels and will thus help the designer to create a space that is visually comfortable. Desk tops, for example, should have a reflectance of between about 35 and 50 per cent. They will then be lower in brightness – but not much lower – than the brightness of most school tasks. A very dark or a glossy white desk top should not be used.

The recommended reflectances are sufficiently high to ensure good utilization of the light falling on them. Much of this light will be reflected, contributing to the illuminance in the classroom.

Table 2/Recommended Reflectance of Surfaces in Learning and Administrative Areas

Ceiling	70-90%
Walls[1]	40-60%
Floor	30-50%
Desk top	35-50%
Chalkboard	up to 20%

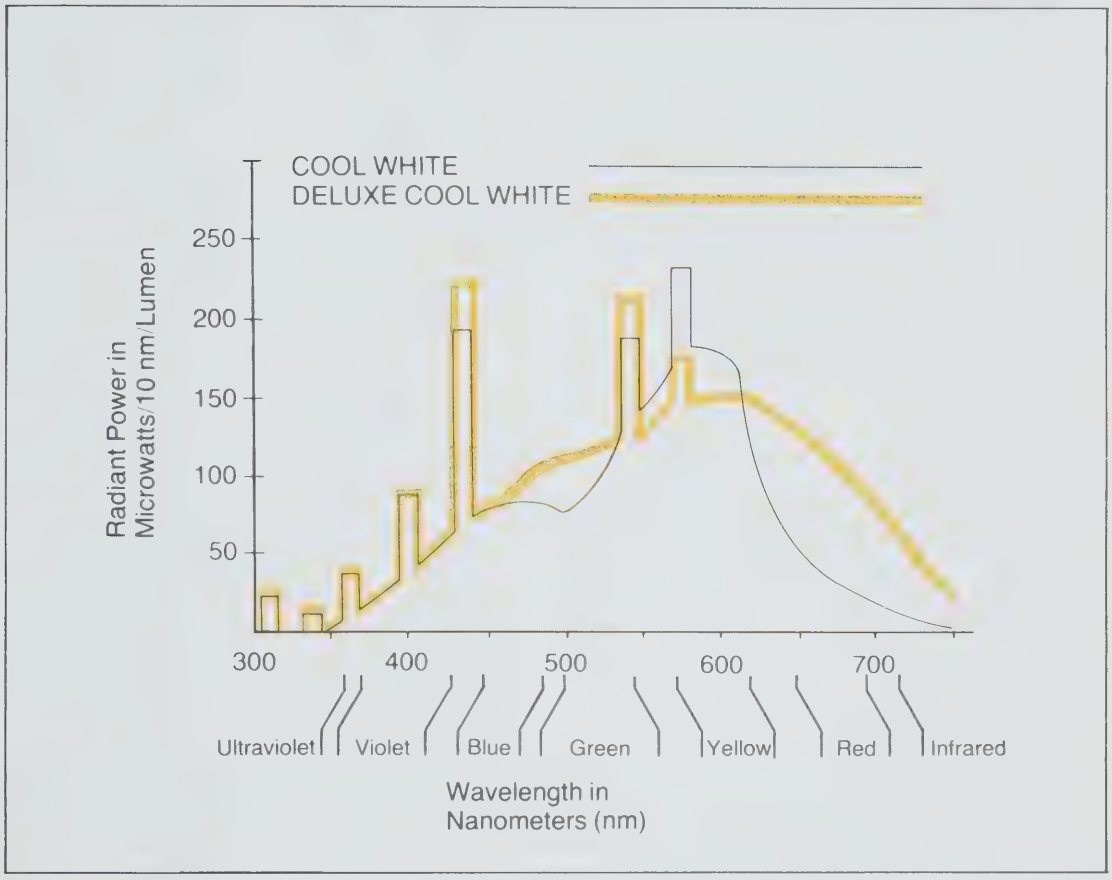
Note:
1. The reflectance of feature and special walls can deviate from this range. The consequence of this must be carefully considered to ensure that the desired overall environment is retained.

Although extreme brightness contrasts in the classroom must be minimized, the use of colour contrasts is recommended. These will ensure that a lively, rather than a bland, environment is produced.

SUMMARY

- The luminance of the principal surfaces greatly influences the visual comfort of a space. The luminance is determined by the lighting system and by what are called the *reflectances* of the principal surfaces. The values of reflectance in Table 2 should be used: they will help to create a space that is visually comfortable.
- Although extreme brightness contrasts must be minimized, colour contrasts are recommended.

Figure 1 / Comparison of Spectra from Cool White and Deluxe Cool White Fluorescent Lamps



If the radiant power is measured in the spectrum from a lamp, a diagram such as the one above can be drawn. This one shows the radiant power emitted by a Cool White (CW) fluorescent lamp and a Deluxe Cool White (CWX) fluorescent lamp. In the CWX lamp, the power in the red part of the spectrum is greater than that in the CW lamp, while the power in the yellow part is reduced. This results in the better colour rendering properties of the CWX lamp: reds seen under the CWX lamp are not greyed as when seen under the CW lamp.

Colour

Colour appearance, colour rendering, and the choice of colours used in decorating

We know from our everyday experience that the way we react to a school space is influenced by the colours used in its decoration. Green interiors – a relic of institutions for the London poor in Victorian times – have been superseded by a wide range of lively, colourful interiors. Yet these colours do not always produce the expected effect. One cause for complaint is that the colours used do not work well with the particular light sources under which they are seen. We must therefore try to ensure that the colours we choose are compatible with the light source.

The appearance of the light source is no help in this choice. The colour of the lamp is no indication of how coloured objects will appear under light from that lamp. Moreover, two lamps may look the same colour – that is, they may have the same colour appearance – and yet make the same coloured surfaces look different. For example, Cool White (CW) and Deluxe Cool White (CWX) fluorescent lamps look much the same. But under the CW lamp, yellows become particularly vivid and reds are greyed; under the CWX lamp these effects do not occur.

The effect of light on coloured objects is known as *colour rendering*. The Colour Rendering Index (R_a) gives an indication of how closely a given light source matches the colour rendering ability of a reference source. The reference source always has an R_a value of 100; the R_a of the given light source varies, for example, from a value in excess of 90 for fluorescent lamps with very good colour rendering, to about 70 for Cool White fluorescent lamps, and down to about 20 for high pressure sodium lamps.

There has been a tendency to use R_a as a figure of merit in comparing one lamp with another; instead, it must be used with caution and the following points borne in mind:

- R_a will be meaningful as a comparison only if it is used with lamps that have substantially the same colour appearance – that is, with lamps that look substantially the same. R_a will not be meaningful as a comparison between, say, Cool White and Warm White fluorescent lamps: these lamps do not have the same colour appearance.
- If the R_a is less than about 90, then the comparison of one R_a with another is of doubtful value.

The R_a is not a particularly useful guide to the selection of lamps for a specific lighting purpose. The only effective way of going about this is to see the lamp in use and to note how well it renders colours.

Similarly, the only effective way of selecting a colour for decoration is to see it under the light source that will be used to illuminate that decoration. Unpleasant-looking interiors can result if this simple procedure is not followed. Yet the procedure can easily be overlooked when repainting a space.

Special care must be taken in the selection of the same colours to be used in adjacent spaces illuminated by different light sources. In these conditions, the difference in the appearance of the colours will be particularly noticeable.

Colour rendering and the choice of lamps for school activities

Good colour rendering lamps are essential for school activities in which the effect of colour has a major impact on the student's response. Art classes are an obvious example. The same applies to cooking classes and to the cafeteria: even the tastiest food can look unappetizing under the wrong lamps.

The use of good colour rendering lamps is also particularly important in the lower grades where children are taught the recognition of colours and their relationship to objects in the world. The children must see colours as they are, otherwise it is possible that their learning will be hindered.

The Lamp Selection Guide (Table 3) summarizes the colour rendering properties of typical lamps suitable for school use.

SUMMARY

- The colour of the lamp is no indication of how coloured objects will appear under light from that lamp.
- The effect of light on coloured objects is known as *colour rendering*. The Colour Rendering Index (R_a) gives an indication of the colour rendering properties of light sources.
- There has been a tendency to use the Colour Rendering Index as a figure of merit in comparing one lamp with another. Instead, it must be used with caution: it is not a particularly useful guide in the selection of a light source for its colour rendering properties.
- The effective way of selecting a colour for decoration is under the light from the source that will be used to illuminate that decoration. Unpleasant-looking interiors can result if this procedure is not carried out.
- If the same colours are to be used to decorate adjacent spaces illuminated by different light sources, then the difference in the appearance of those colours under the different sources will be particularly noticeable.
- Good colour rendering lamps are essential for a number of school activities – art, cooking, and teaching the lower grades – and in the cafeteria.

3. Lamps and Ballasts

Lamps

Three categories of lamps are used for school lighting: incandescent, fluorescent, and high intensity discharge. The Lamp Selection Guide (Table 3) gives the design characteristics of lamps in each category.

Incandescent lamps

The incandescent lamp is the one in common household use. It consists of a filament of fine, coiled tungsten wire enclosed in a glass bulb which is usually filled with a mixture of nitrogen and argon. Electric current passing through the filament heats it until it gives off light.

One variation of the incandescent lamp is the tungsten-halogen lamp. Here the filament is usually in an atmosphere of iodine vapour instead of the nitrogen and argon mixture. The effect of the iodine vapour is two-fold: it prevents the lamp bulb from darkening as quickly as in other incandescent lamps, and it prolongs the filament life. Consequently, the light output is maintained better and the lamp life is longer than in a standard incandescent lamp. The tungsten-halogen lamp may be used for display purposes. However, it costs much more than a standard incandescent lamp of approximately the same wattage.

The efficacy of the incandescent lamp – that is, the lumens of light emitted per watt of power – increases as the lamp wattage increases. Also, the efficacy and the lamp life affect one another. Efficacy can be increased if a shorter lamp life is acceptable; a longer life can be achieved by a reduction in efficacy. For example, a standard 100 W lamp has a rated life of 750 hours and the extended-life 100 W lamp a rated life of 2500 hours. The increase in life is achieved at the expense of a drop in efficacy from 17.5 lm/W to 15 lm/W.

The *rated life* of an incandescent lamp does not mean that every lamp, when operated correctly, will burn for that length of time – for example, 750 hours in the case of the standard 100 W lamp. Some lamps will burn for a longer time than the rated life and some for a shorter time. At the rated life, 50 per cent of the lamps in a large installation will have failed. This is a significant point to bear in mind when considering lamp replacement. All too frequently it has been assumed that all the lamps will burn for the rated life, and the lamp replacement program has been based on that assumption. In addition to the problems caused by incorrect estimates of lamp replacement costs, this results in burnt-out lamps appearing in an installation. These will spoil the look of the installation and also reduce its effectiveness.

Some luminaires may be operated with more than one type of lamp and possibly much more efficiently with one lamp type than with another. For example, a baffle downlight will produce about the same illuminance with a 75 W ellipsoidal reflector lamp as with a 150 W reflector flood lamp.

Fluorescent lamps

The fluorescent lamp consists of a glass tube containing mercury vapour and with electrodes at each end. The inside of the tube is coated with a powder (i.e., the phosphors). An arc flashes to and fro between the electrodes, producing invisible ultraviolet radiation together with a little visible blue light. The radiation falls on the phosphors coating the tube, causing them to fluoresce and give off light. Most of the ultraviolet radiation is thus absorbed by the phosphors and the glass tube; little is emitted by most lamps.

Light of almost any colour can be produced by using the appropriate phosphors: something like three dozen "white" lamps alone appear in the catalogues. It has already been mentioned that two fluorescent lamps may look the same colour yet have different colour rendering properties. Usually, but not always, the lamp output falls as the colour rendering improves.

Fluorescent lamps range in size from 4 W to 215 W. Reduced wattage lamps have been introduced in the past few years. They use 10 to 20 per cent less power than the corresponding standard fluorescent lamps, depending on size. One such lamp is the 4-foot 35 W Rapid Start lamp which can be simply substituted for the common 4-foot 40 W Rapid Start lamp without change of ballast.

A fluorescent lamp cannot be operated without a ballast – usually two lamps from one ballast. Special ballasts are available by which fluorescent lamps can be dimmed. There are also multi-level ballasts which enable the light output to be reduced by a simple reconnection of the ballast leads.

Table 3 / Lamp Selection Guide

Lamp Name	Sunlight Simulating and Colour Matching Fluorescent	Cool White Fluorescent	Deluxe Cool White Fluorescent	Warm White Fluorescent
Approx. Correlated Colour Temp.(K)	5000- 5500	4400	4000	3100
Lamp Colour Appearance	Bluish- White	White	White	Yellowish- White
Colours Strengthened	All Nearly Equal	Orange Yellow Blue	All Nearly Equal	Orange Yellow
Colours Greyed	None Appreciably	Red	None Appreciably	Red Green Blue
Approx. Initial Luminous Efficacy (lm/W)	55-72	80	55-72	80
Approx. Rated Life (Hours)	(a) 12 000- 20 000	(a) 12 000- 20 000	(a) 12 000- 20 000	(a) 12 000- 20 000
Remarks	Very good colour rendering. Light appears cold at low illuminances.	Acceptable for most applications where colour rendering not important. Light appears cold at low illuminances.	Use where good colour rendering important. Light appears cold at low illuminances.	Acceptable for most applications where colour rendering not important. Light appears warm.

Notes:
(a) According to type, 3 hours per switching.
(b) According to type.
(c) According to type, 10 hours per switching.
(d) 5 hours per switching.

The life of a fluorescent lamp – unlike that of an incandescent lamp – is affected by the number of times it is switched on and off. The life is rated by the number of hours the lamp is allowed to remain alight after being switched on: the longer it remains alight the longer the life. For example, the life may be rated at 20 000 hours, assuming that the lamp operates for three hours per switching. As with incandescent lamps, at the rated life, 50 per cent of the lamps in a large installation will remain alight.

As a general rule, if fluorescent lamps are not to be used for five minutes or more, they should be switched off.

Dummy lamps

A dummy lamp looks much like a standard fluorescent lamp but it gives off no light. It is a device which can be substituted for one of the two lamps (usually 4-foot 40 W Rapid Start lamps) operated by one ballast: the two-lamp ballast remains without alteration to the circuit, but only one lamp emits light. The use of a dummy lamp results in a substantial drop – of about one-third – in the light output from the other lamp. There is also a drop of about three-quarters in the power drawn by the two-lamp ballast.

High intensity discharge (HID) lamps

There are four types of HID lamps: mercury, metal halide, high pressure sodium, and low pressure sodium.

HID lamps, with the exception of the low pressure sodium lamp, have been found acceptable for school locations where colour rendering is not important – in gymnasia and workshops, for example.

Deluxe Warm White Fluorescent	Incandescent	Deluxe Mercury	Phosphor Coated Metal Halide	High Pressure Sodium	Low Pressure Sodium
3000	3000	3400	3500	2200	–
Yellowish- White	Yellowish- White	Purplish- White	Purplish- White	Yellowish	Strong Orange
Red, Green Orange Yellow	Red Orange Yellow	Red Yellow Blue	Red Yellow Blue	Yellow Orange Green	Yellow Orange
Blue	Blue	Green	Green	Red Blue	All Except Yellow and Orange go Brown-Black
55-72	20	55	85	120	180
(a) 12 000- 20 000	(b) 750-2500	(c) 16 000- 24 000	(c) 7500-20 000	(c) 24 000	(d) 18 000
Colour rendering not quite good enough where colour rendering important. Light appears warm.	Good colour rendering.	Similar to remarks for cool white fluorescent lamp.	Similar to remarks for cool white fluorescent lamp.	Similar to remarks for warm white fluorescent lamp, but lamp with poorer colour rendering.	Poor colour rendering makes use unlikely for school interiors, but may be used for exteriors.

Mercury lamps

A mercury lamp consists of two envelopes: the outer glass bulb and the inner (and much smaller) arc tube. The arc tube contains mercury vapour which emits light when an electric current passes through it forming an arc. Ultraviolet radiation is also emitted. This radiation falls on phosphors coating the inside of the outer bulb, causing them to emit light. The light from a mercury lamp is thus a combination of that from both the arc tube and the phosphors.

Metal halide lamps

The metal halide lamp is similar in construction to the mercury lamp. The main difference is that its arc tube contains metal halides in addition to the mercury vapour. These change the colour of the light emitted from the arc tube from the blue of the mercury arc to white. The colour is further improved in some lamps – those that would probably be used in schools – by coating the inside of the outer bulb with phosphors, as in the mercury lamps.

The efficacy of the metal halide lamp is 1½ to 2 times that of the mercury lamp.

High pressure sodium lamps

The high pressure sodium lamp has two envelopes. The outer is of glass and the inner arc tube, which contains sodium, is of alumina, a material that is much more resistant to sodium attack at high temperatures than glass. The light from this lamp is usually described as being "golden-white".

Low pressure sodium lamps
The low pressure sodium lamp has two envelopes. The inner – the arc tube – is of special non-staining glass. It contains some metallic sodium and a gas, usually neon. The outer envelope is a vacuum jacket, similar in principle to a Thermos flask. Its purpose is to keep the discharge in the arc tube at its optimum operating temperature.

The low pressure sodium lamp is not suitable for school lighting. It gives off yellow light which turns every colour it falls on either yellow or muddy.

Operating characteristics of HID lamps
A ballast is required to operate HID lamps. Ballasts are available which enable some lamps to be dimmed.

With the exception of the low pressure sodium lamp, all HID lamps have similar operating characteristics. Each lamp takes a few minutes (from one to seven according to lamp type) to come up to full light output after being switched on. Then, if the power is switched off momentarily and switched on again, it will take from two to fifteen minutes before the lamp gives off its full light output. Thus HID lamps must not be used where light is to be provided immediately at the flick of a switch. Where HID lamps are used, a few incandescent or fluorescent lamps, which emit their full light output immediately on switching, are frequently included in the installation. These provide some light during the period in which the HID lamps are building up to their full light output.

The life of an HID lamp is much more affected by switching than that of a fluorescent lamp: with HID lamps, in particular, the less they are switched on and off, the longer their life. The life is rated by the number of hours the lamp is allowed to remain alight after being switched on. For example, the life of a mercury lamp may be rated at 24 000 hours, assuming that the lamp operates for ten hours per switching. At the rated life, 50 per cent of the lamps in a large installation will remain alight.

As a general rule, if HID lamps (excluding low pressure sodium lamps) are not to be used for one hour or more, they should be switched off.

SUMMARY
- At the rated life of a lamp, only 50 per cent – not 100 per cent – of the lamps in a large installation will remain alight.
- The life of fluorescent and high intensity discharge (HID) lamps is affected by the number of times they are switched on and off.
- The life of HID lamps is much more affected by switching than that of fluorescent lamps: with HID lamps, in particular, the less they are switched, the longer their life. Switch off fluorescent lamps if they are not going to be used for five minutes and HID lamps if they are not going to be used for one hour. Incandescent lamps may be switched at will: their life is not affected by switching.
- HID lamps take a few minutes to come up to full light output after being switched on. They must not be used alone where light is needed immediately at the flick of a switch. A few incandescent or fluorescent lamps in an installation of HID lamps will provide light while the latter lamps are building up their light output.
- Refer to the Lamp Selection Guide (Table 3) when choosing a lamp for a particular school area.

Ballasts

A ballast is required to operate both fluorescent and HID lamps. The device has two functions. First, it limits the flow of current through the lamp: without the ballast the current will increase and very quickly destroy the lamp. Secondly, it provides a voltage sufficiently high to start and maintain the arc discharge.

The heart of a present-day ballast is a core made of thin steel stampings surrounded by a coil of copper wire, similar to a transformer. It is anticipated, however, that within the foreseeable future, solid state ballasts will supersede the present type of ballast.

Ballasts consume energy. For example, there is a loss of about 16 W in a standard ballast for two 40 W Rapid Start fluorescent lamps: the total power drawn by the ballast plus lamps is thus 96 W.

New types of ballast, which offer certain advantages over the standard ballast, are now available. Some of them are as follows:

- A ballast for two 40 W Rapid Start fluorescent lamps which has a loss of about 9 W instead of the 16 W of the standard ballast: the total wattage drawn by the ballast plus lamps is thus 89 W. There is no loss of lamp light output with this ballast, but it costs more than the standard ballast.
- A ballast for two 40 W Rapid Start fluorescent lamps which, with the lamps, draws total power of about 67 W. There is a drop in lamp light output of about 30 per cent.
- A ballast for two 40 W Rapid Start fluorescent lamps which can provide either 100 per cent or about 60 per cent of the light output from the lamps by a simple reconnection of the ballast leads. The power drawn by the ballast plus lamps will be about 96 W or 57 W respectively.
- Ballasts for use in dimming circuits for fluorescent, mercury, and metal halide lamps.

Solid state fluorescent lamp ballasts will be available in the foreseeable future. These will have the following advantages compared with present-day ballasts:

- much lower wattage loss
- the ability to operate the lamps at high frequency so that they give off more light – the light output from a fluorescent lamp increases with the lamp operating frequency
- no audible hum

All present-day ballasts hum to a greater or lesser extent. The hum is usually, although not always, louder as the lamp wattage increases, and may be amplified by the way in which the ballast is mounted in the luminaire.

Ballast hum can be disturbing, although a hum that disturbs the quiet of a library will not be heard in a woodworking shop. Guidance is given by individual manufacturers on the suitability of their ballasts for use in various types of locations, some noisy, some quiet. There is, however, no industry standard indicating the degree of hum made by different types of ballast.

SUMMARY

- A ballast is required to operate fluorescent and HID lamps. In addition to those for normal lamp operation, special ballasts are available which reduce the wattage drawn by (and thus the light output from) fluorescent lamps, and which permit fluorescent and HID lamps to be dimmed.
- Ballasts consume energy.
- Present-day ballasts hum to a greater or lesser extent. The hum can be distracting.

External louvres prevent direct sunlight from entering into the classroom.

Sheridan College, Oakville Campus, Oakville
Marani Rounthwaite & Dick, Architects

PHOTO: OMER BURZDZUS

4. Windows and Daylight

Windows have usually been considered an advantage in a school. They let light in and enable students and staff to see out. There is an instinctive desire for contact with the outside. Yet, by contrast, teachers in a windowless school have referred approvingly to "no direct sunshine; no glare; no outside disturbances – noise, weather conditions".

The Effectiveness of Windows

How effective are windows in modern schools in providing light by which to work and study? There is a great need to collect data on the amount of daylight available for interior lighting and the extent to which it can reduce lighting and HVAC* costs. There is also a need to improve the techniques by which interior daylighting is predicted: any prediction using existing techniques will be of limited accuracy.

With these comments in mind, consider a traditional cellular classroom about 9.1 m (30 ft) by 7.6 m (25 ft) by 2.7 m (9 ft), with windows 2 m (6 ft) high from sill to ceiling running along one wall. For many normal-length working days, there will be enough daylight by which to work over about a 3 m (10 ft) width of the classroom measured in from the windows. Thus if, as is common, the classroom is illuminated by three rows of fluorescent luminaires parallel to the windows, the row nearest the windows can be switched off much of the time.

Screening Devices for Controlling Glare and Sunlight

Windows are capable of producing both disability and discomfort glare. The former, which results in reduced visibility and visual performance, is caused by direct sunlight or the reflection of that sunlight. The latter may be caused by a view of clouds or the blue sky – often referred to as "sky glare". Attempts to alleviate sky glare by reducing the window size may result in an increase in discomfort depending upon the location of the windows. Blinds and drapes are usually a more effective means of controlling that glare.

Direct sunlight also causes another problem: a build-up of heat in the classroom. One square metre of unshaded window can transmit solar radiation equivalent in heating power to one square metre of steam radiator. Moreover, a change in the characteristics of the solar radiation, which occurs when it falls upon interior surfaces, traps much of the radiation inside the room – it is unable to escape back through the window. As a result, the temperature in the classroom rises, an effect known as the "greenhouse effect". (On the other hand, some of the heat actually produced in the classroom – by the HVAC system, by the lighting system, by the people in the room – will escape to the outside unless something is done to prevent it.)

Sunlight may be controlled by external louvres, by interior drapes, and by devices sandwiched between double glazing. Louvres are the most effective: it is always best to control the sun before it reaches the glass. The possibility of maintenance problems from ice and snow must be borne in mind when considering the use of external louvres.

In the northern hemisphere, both glare and heat build-up may be expected from south- and west-facing windows. Heat from the latter windows can be of unexpected severity since the rays of the sun pass through the glass with only little loss by reflection at its surface. Horizontal louvres can be designed for south-facing windows so that the sun is screened in summer (when high in the sky), but is allowed to reach the windows in winter (when at a low angle). Vertical shading devices work best on windows facing approximately east and west.

Inadequate window design and the lack of screening devices could mean that daylight cannot be used, simply because of the sun glare. Drapes will have to be drawn for visual and thermal comfort, and electric lighting used instead.

Any screening device – particularly interior drapes – must be so chosen that it does not become too bright and cause glare when the sun shines on it. On the other hand, at night the device must not appear dark, otherwise it will create excessive contrast with the other surroundings in the room.

* Heating, ventilating, and air conditioning.

Aspects of Daylighting Design

In a new school, windows and daylight will be considered as an element in lighting design additional to the electric lighting. Good daylighting design does not simply mean large windows. It must be approached both quantitatively and qualitatively on broad and sensitive design terms.

The quantitative design of windows is straightforward. It involves:

- building orientation – the direction the windows face
- the size, shape, and glazing of windows
- sunlight control
- the trade-off between energy saved by using daylight instead of electric light and the heat loss and heat gain through the windows
- an assessment of the cost of vandalism

Life-cycle costing may be applied to the window design so that the windows provide the best return on investment. Such costing will make it clear that daylight is not free.

In contrast to the quantitative design of windows, the qualitative design is complex. Consideration must be given to matters for which there are no firm design guidelines. So far the significant conclusion of studies aimed at evaluating whether or not schools should have windows is that there is no significant conclusion.

The advantages of the windowless school are that it eliminates window breakage and outside distractions and reduces vandalism, excessive glare, and wasted wall space. Its disadvantages are viewed as primarily psychological. It has been perceptively pointed out that people bring their attitudes and prejudices to a building. Their past experience is an essential part of the perceptual translation and one ignores it at one's peril. Why should we want to ignore these deeply held beliefs?

If staff and students believe that rooms should have windows, then it seems likely that rooms will have to have windows. However, considerations of both the qualitative and quantitative aspects of design may show that the windows can be small and provided as a pleasant amenity rather than as a main contributor to the lighting of the room.

Lighting and Health

Studies on the effect of light on humans are inconclusive. Although experiments on animals have received considerable scientific discussion, it is difficult to understand how significantly these findings can be applied to human beings. Our understanding of both the healthful and harmful effects of light has been influenced by conjectural and speculative reporting. The comments below outline the present state of knowledge on some of the effects of light on health.

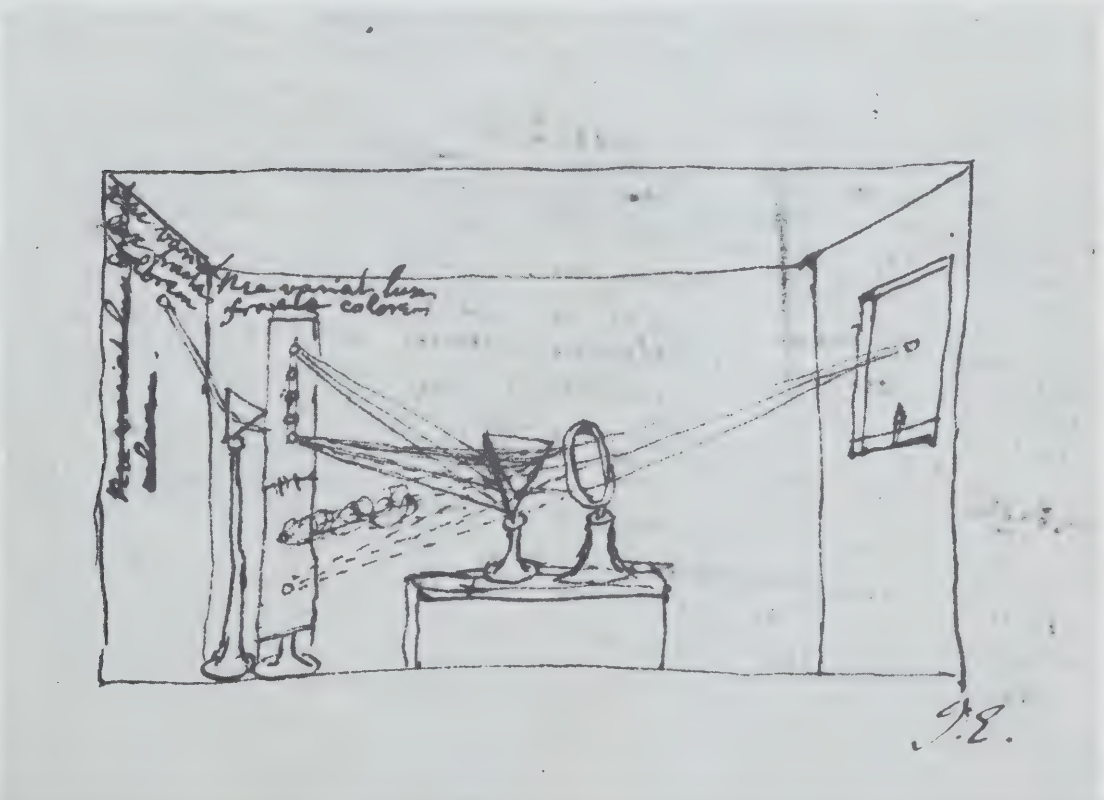
But first, a general comment on the nature of electric light and sunlight: As Newton found in his famous experiment of 1666, a rainbow or spectrum is formed when sunlight is passed through a prism. The wavelengths of the visible light forming that spectrum extend from 380 nanometers (blue light) to 760 nanometers (red light). Ultraviolet radiation and infrared radiation are also found in sunlight. It is important to recognize that all of the wavelengths of any lamp, both old and new, are present in sunlight. Not every lamp emits light in all the wavelengths present in sunlight, but no lamp emits light of a wavelength that is not in sunlight.

Ultraviolet radiation and health

Ultraviolet (UV) radiation affects our health (and also causes suntan). It is present in the sun's rays as well as in many commonly used lamps, including fluorescent, HID, and some tungsten-halogen lamps. Not all lamps emit the same UV radiation per watt of power. There is even considerable variation in the UV radiation from the various types of the common 4-foot 40 W fluorescent lamp. (See Appendix 2 for additional statements on ultraviolet and health.)

The design of a luminaire and the materials used in its construction determine the amount of UV radiation it emits. For example, anodized aluminum is a good reflector of the radiation, whereas glass and many paints absorb it. Thus an open luminaire with an anodized aluminum reflector will emit much of the UV radiation from the lamp; a luminaire with a painted reflector and a glass front will emit little of the radiation.

The absence of UV radiation can be harmful to health, since it can cause a deficiency in vitamin D, the vitamin needed to develop strong bones. In severe cases, bone diseases such as rickets may result. Rickets is in fact the earliest air pollution disease: it



Newton's sketch showing the formation of a spectrum.

Reproduced by kind permission of the Bodleian Library, Oxford.

was first described in England in 1650. It has been directly attributed to smoke from the coal fires in Europe's industrial cities which blocked the UV radiation from the sun. Nowadays, however, many foods are fortified with vitamin D additives, and a normal diet will provide enough vitamin D without the need for UV radiation.

Too much UV radiation, as well as too little, can be harmful. If the outer bulb of a mercury or metal halide lamp is broken, the lamp may not be extinguished: it may continue to give off both light and UV radiation from the arc tube. If the lamp, with its broken bulb, is housed in an open reflector – particularly an open aluminum reflector – then that reflector may concentrate the UV radiation. The concentration of that radiation may well harm the eyes of someone who looks directly at the luminaire.

Special types of mercury and metal halide lamps are available which extinguish themselves automatically if the lamp bulb is broken. It is recommended that these be used unless the lamp is protected from breakage.

HID lamps in schools

Many successful school lighting installations use HID lamps. However, from time to time there has been adverse reaction to these lamps, particularly to high pressure sodium lamps in general use at the time of writing. The lamps have been criticized on the grounds of:

1. the colour of the light from the lamps;
Accurate colour discrimination is impossible under HID lamps. The colour of paint used for art is distorted, flesh tones are changed, and food can look unappetizing.

2. the glare they cause;
Glare is not unique to HID lighting. It can be caused by any form of lighting.

3. the time the lamps take to burn brightly – that is, the lamp striking time;
HID lamps are not suitable where light is needed instantly at the flick of a switch.

4. their possible health effects.

The phenomena of glare and colour rendering, and the operating characteristics of HID lamps, are well known. That they in particular give rise to complaints points to the incorrect use of the lamps and emphasizes the need for good lighting design. It is also worth remembering that lamps are constantly improved in colour, efficacy, and performance. It may be found that an improved lamp can be used in a location previously denied to earlier lamps of the same type.

As far as the health effects of HID lamps are concerned, the studies conducted have been inconclusive. Laboratory studies, specifically with high pressure sodium lamps, have led to the conclusion that there may be unexpected effects on the user impression of clarity with these lamps. But there is no clear understanding of this phenomenon or of the extent of the problem.

Lamp colour rendering and the choice of illuminance

It is sometimes stated that when one uses good colour rendering lamps, the illuminance in a working space can safely be less than the illuminance needed when lamps of poorer colour rendering are used. This statement is incorrect. It has resulted from lack of understanding of a classic experiment on "visual clarity" by Aston and Bellchambers. There is no evidence to show that the illuminance for a visual task depends on the colour rendering properties of the lamps used to light that task.

Loss of muscle strength under various light sources

Although there are suggestions to the contrary, there is no good scientific evidence that muscle strength is affected by the visible light spectrum and the presence or absence of ultraviolet radiation. In other words, a student's muscle strength is not affected by the type of lamp used to illuminate the school.

Lamp flicker

Fluorescent and HID lamps tend to flicker as they get old. Children are much more sensitive to flicker than adults. The onset of flicker may well be the signal to change a lamp even though it has not reached the end of its rated life.

Fluorescent lighting and hyperactive children

Present data are inconclusive on any connection between hyperactivity in children and the use of fluorescent lighting in classrooms.

Student tiredness

There is some evidence to suggest that students working under fluorescent lighting with very good colour rendering become less visually fatigued than those working under some other forms of fluorescent lighting. There is no evidence on how this reduction in visual fatigue affects the general fatigue and work performance of students.

The windowless school

The windowless school is a radical departure from the conventionally designed school. Accordingly, a number of researchers have investigated the reaction of staff and students to their windowless environments. The results have been summarized as follows:

> If any single conclusion is to be reached from the studies of windowless schools it is that the absence of windows neither improves nor impairs [scholastic] performance. Although some students like the [windowless environment], others, possibly a majority, would prefer to have windows. The most striking conclusion seems to be absence of significant findings, either for or against. Whether this is the fault of the experimental designs used, or a reflection of the real absence of any pronounced effect, is not known. Yet the absence of enthusiasm for the windowless school suggests that it should be used with some caution, particularly since its long-term effects are unknown.*

Special Lighting Requirements

Lighting for areas with visual display units (VDUs)

The viewer screen of a VDU behaves something like a mirror. Reflections of bright surfaces (a luminaire or a window, for example) on the screen will dilute, or even obscure, the images of the data appearing on it. This means that the operator must make an extra seeing effort or adopt an awkward posture in order to read the data presented on the screen. The lighting must therefore be designed so that reflections of bright surfaces are not seen in the viewer screen.

It is also necessary to avoid too high a brightness contrast between the viewer screen and other surfaces (such as a window or desk top), otherwise the eye will tire as it adapts first to one brightness and then to the other.

Consequently, the location of the VDU must be chosen so that no reflections of bright surfaces (luminaires, walls, windows) are seen in the viewer screen. Furthermore, the VDU operator must not have a direct view of a bright surface, particularly a window.

In many situations the VDU operator looks first at the source documents and then at the viewer screen. In order to keep down the brightness contrast between the screen and the other surfaces at the work station, a general illuminance of about 250 lux should be provided at the work station, and an illuminance of 500 lux on the source documents (probably by a local light). The top of the work station should have a reflectance of about 30 to 40 per cent.

Lighting for plant growth

Many types of incandescent, fluorescent, and HID lamps are used to grow plants indoors. The lamps used, either alone or in combination, must produce light with a proper colour balance if normal plant growth and shape is to result. Particular attention must be paid to ensuring that there is enough energy in the red and blue parts of the spectrum. A wide spectrum fluorescent lamp is made to meet the special requirements of plant growing.

*Belinda L. Collins, "Review of the Psychological Reaction to Windows," *Lighting Research and Technology*, vol. 8, no. 2 (1976), p. 81.

Manual switching: If there is enough light, the rows of luminaires nearest the windows may be switched off.

6. Switching and Energy Management in Lighting Systems

It is quite common to find that luminaires are left on in an unoccupied space or in places where daylight provides adequate light. In fact, overuse of lighting systems most frequently occurs because luminaires are not switched off, and not because they are switched on unnecessarily.

Switching is a vital element in lighting system design. If the provision of switches is skimped, all the lighting in a large space may be controlled by one switch. This means that all the lighting will be left on even though part of the space may receive adequate daylight or even though only part of the space may be in use. The consequences in terms of energy costs are obvious.

Manual Switching

Manual switching should at least permit separate control of the rows of luminaires parallel to the windows, since these can be switched off for much of the time during normal school hours.

It is relatively expensive to provide additional manual wall switches to an existing lighting system. It may be possible, however, to rearrange existing switching so as to provide more flexible control of the lighting.

Pull cord switches may be put to use in, say, a school office. They can be provided less expensively than wall switches.

Time Controls

If a school ceases to be occupied at a fixed time each day, it may be worthwhile installing a time control to switch off most of the lights shortly after that time. The time control should have an override device to permit the lighting to be switched on should it be required after the usual fixed time.

A low-cost electronic timer has been developed for direct fitting into a standard wall box to replace a conventional manual wall switch in individual classrooms. The timer is programmed for 15, 30 or 60 minutes' light.

Photoelectric Controls

Daylight entering through large windows can provide enough light in part or all of a classroom for part of the day. Photoelectric control can ensure that the electric lighting can neither be switched on nor remain on if daylight provides the required illuminance. A photoelectric sensor measures the illuminance provided by daylight at a chosen location or locations in the classroom. When that illuminance reaches a predetermined level, the control switches the electric lighting either on or off.

Photoelectric control is not suitable for switching high intensity discharge (HID) lamps because of their starting characteristics. It may, however, be used to control these lamps on a continuously variable dimming circuit.

Where photoelectric control is used, an override switch should be provided to ensure that no lights are left on when the classroom is unoccupied.

On-off photoelectric control
The control switches off the electric lighting when the illuminance produced by daylight is about equal to that produced by the electric lighting system. Similarly, when the illuminance from the daylight falls below a certain level, the control switches the electric lighting back on. Consequently, when switching occurs, the illuminance in the space is suddenly just about halved or doubled, depending on whether the illuminance from the electric light is subtracted from or added to the illuminance from the daylight.

There is considerable evidence that the occupants of a space find this sudden change in illuminance of 50 or 100 per cent unsatisfactory when large areas are controlled in this way. However, it appears to be more acceptable if, for example, photoelectric control is applied to the row of luminaires nearest the window. This is mainly because switching this row will be infrequent.

Top-up photoelectric control
Equipment is available which will automatically vary the light output from – and thus the illuminance produced by – incandescent, fluorescent, and HID lamps. This equipment is controlled by a photoelectric sensor so that the illuminance from the electric lighting tops up that from daylight when the daylight fails to reach the desired illuminance level. As the daylight fades, the electric lighting increases; as the daylight gets brighter, the electric lighting is reduced.

This method of control uses less energy than the on-off photoelectric control.

Special ballasts are required for the fluorescent and HID lamps.

Occupancy Detector Control

An occupancy detector senses the presence of people in a space. If nobody is there, the lamps are either dimmed or switched off, depending on the circuit used. There is usually a time delay between the last person leaving the space and the lamp switching. However, when a person enters the space, the lamps come on immediately.

Monitoring Lighting Use: The Elapsed-time Meter

The elapsed-time meter records the number of hours an electric lighting system has been in use over an extended period of time. It can thus be used to calculate the energy consumed by the lighting system over that period.

The record of the lighting system use must not of course include other uses of electric energy, such as office equipment, tools, and machinery. The usual approach has been to wire a separate meter into each lighting circuit being studied. But this is expensive and inconvenient.

An alternative elapsed-time meter has been developed by the National Research Council of Canada. This meter uses a photoelectric device to record lighting use. It does not have to be wired into an electric circuit: instead, it is simply mounted on a convenient surface near the luminaires being studied. The meter will sum the number of hours the electric lighting has been provided.

7. Making the Most of Your Lighting System: Basic Considerations

Before attempting to make your present lighting system more effective and energy efficient, ask yourself this question: Is the lighting system a good one and appropriate to the space? If the system is neither effective nor in good shape, consider replacing it.

The first step in making an appraisal of the present system is to measure the illuminance – the light level – in the various spaces. A light meter measuring to an accuracy of about ± 10 per cent will be adequate. (This accuracy will not be achieved with the cheapest light meters.) The illuminance in a space will vary from place to place: the degree of variation depends on the luminaire light distribution, the luminaire spacing, and the mounting height.

Compare the measured illuminances with those recommended in Table 1. There is no need for the two sets of illuminances to line up exactly since the eyes perform satisfactorily over a wide range of conditions.

Other aspects of the lighting system that should be investigated are as follows:

- the amount of glare caused by the lighting; Does the lighting suddenly become more comfortable if you shade your eyes with your hand? If so, there is too much glare.
- the colour rendering characteristics of the lamps; Are some colours accentuated or made to look dull or otherwise unacceptably distorted? Is there a need for lamps with particularly good colour rendering (e.g., in an art classroom)?
- the general condition of the luminaires; Have the luminaires been poorly maintained, with cracked, discoloured or missing lenses, and reflectors with ground-in dirt?
- the location of the working positions with respect to the luminaires and windows.

If you have decided that the present lighting system is worth retaining, a number of procedures can be adopted which will enable you to save energy consumption and costs as well as increase the effectiveness of the system. Some of these procedures can be carried out without any capital investment; others will require some additional outlay, but they can be expected to pay for themselves within a fairly short time.

Whatever you do, remember that the most efficient way of saving electrical energy – and the cost of that energy – is to *switch off the lamps when they are not required.*

Incandescent lamps should be switched off as soon as they are not required: their life is not affected by the number of times they are switched. Switching does, however, affect the life of fluorescent and high intensity discharge (HID) lamps. Accordingly, a compromise must be reached between the energy saved by switching and the reduction in lamp life – with the consequent earlier lamp replacement – resulting from the switching. Remember that as a general rule, if fluorescent lamps are not to be used for five minutes or more they should be switched off; if HID lamps are not to be used for an hour or more they should be switched off.

Procedures requiring no capital investment

1. Remove unnecessary luminaires.

It is recommended that the luminaires be removed rather than just the lamps (as is frequently suggested) because a number of luminaires without lamps will look unsightly and could spoil the appearance of the space concerned. A lighting system that looks makeshift today will go on looking makeshift for the next fifteen years unless something is done about it.

However, it may not be possible to remove luminaires, but only lamps. If these are fluorescent or HID lamps, the ballasts in the luminaires should be disconnected since they will continue to consume energy even if no lamps are connected to them. For example, a commonly-used ballast for two 40 W Rapid Start fluorescent lamps will continue to draw about 16 W.

If the luminaires are in rows and a uniform illuminance is required, remove alternate luminaires in each row rather than all the luminaires in one row. Check the illuminance once the luminaires have been removed.

2. Replace lamps which are beyond their useful life.

A badly blackened fluorescent lamp, for example, will produce just a fraction of its rated light output.

3. Keep the luminaires clean and replace discoloured lenses.

4. Locate the work positions to take advantage of daylight.

Procedures with short pay-back period

1. Convert to more efficient lamps.

In general, it can be said that with the ever increasing cost of energy, the most efficient lamp will be the least expensive in the long run. However, more than efficiency alone must be considered before a conversion program is started. Other factors include:

- the cost of the lamp (and its ballast if one is required)
- the colour appearance and colour rendering properties of the lamp
- the ability of the luminaire to accept the new lamp, or the cost of modifying the luminaire to permit it to do so, or the cost of a new luminaire
- the light output of the lamp in relation to the illuminance required

2. Use more efficient ballasts.

New ballast designs have resulted in more efficient ballasts. For example, a luminaire for two 40 W Rapid Start fluorescent lamps that uses a standard ballast will draw a total of 96 W or more; using the new ballast, it will draw only 89 W.

Solid state ballasts for fluorescent lamps will become available in the foreseeable future. They will consume less energy and operate the lamps more efficiently than any present-day ballasts.

Carefully review the pay-back period when converting to the more efficient ballasts.

3. Use dummy fluorescent lamps.

A dummy ("phantom") lamp may be used to replace one of the two 40 W Rapid Start fluorescent lamps operated by a single ballast. The dummy lamp gives off no light and consumes no energy. Its use reduces the power drawn by the luminaire from about 96 W to about 36 W.

4. Replace fluorescent lamps with lamps of lower wattage.

The 4-foot 40 W Rapid Start fluorescent lamp may be replaced by the 4-foot 35 W Rapid Start fluorescent lamp in most (but not all) luminaires without change of ballast. This will result in a reduction in light output (and thus of illuminance) of about 10 per cent. The power drawn by the luminaire, using a standard ballast, will be reduced from about 96 W to about 86 W.

5. Improve switching.

The simpler forms of switching systems discussed in section 6 could be considered.

6. Repaint school spaces.

Paint finishes should have the reflectances specified in Table 2. This will ensure that much of the light will be reflected by the principal surfaces (thus contributing to the illuminance), and will help create a space that is visually comfortable. The finishes should be chosen under the light from the lamps which will normally be used. If this is not done, unexpected (and unpleasant) changes in the appearance of the finishes may result.

7. Provide light coloured blinds to reflect the sun's heat back through the windows.

The blinds must be light in colour and must be kept clean, otherwise the sun's heat will be absorbed and then re-radiated into the space and warm it.

Procedures with long pay-back period

Providing a sophisticated lighting control system would entail a longer pay-back period than the procedures discussed so far. This system would be integrated with an automatic energy control system. The lighting controls should probably top up the daylight in spaces with windows rather than provide only on-off control. (These controls are discussed in section 6.)

Finally, a new lighting system could be installed. The new lighting system should be tightly designed so that it conforms closely to the design criteria. This will require more design skill than much of that displayed up to now: it has not been unusual, for example, to find illuminances 25 per cent higher than their design value, which means that 25 per cent more energy than necessary is being used.

Skilful design will require accurate information on the lamp light output, luminaire efficiency, the finish of surfaces, and space layout. It may also require ceiling systems that permit more precise location of luminaires than many existing ceiling systems. The designer should pay as much attention to the quality of the lighting and the ambience it produces as to the technical aspects of the design.

8. Exterior Lighting

Exterior lighting is primarily intended for night-time access: pathways to the school (and people on and near the pathways) are clearly distinguished; car parking is facilitated. The lighting can be provided by luminaires mounted high up on the school building and directed outwards. These may be supplemented (or, sometimes, supplanted) by pole-mounted luminaires illuminating the paths and their immediate surroundings and the parking area. The illuminances and the lamps recommended for good contemporary residential street lighting are appropriate for school exterior lighting. The lighting must clearly identify steps and changes of level.

Lighting for a landscaped campus must do more than meet the requirements of access. It must also be in harmony with the landscape. A landscaped campus presents many interesting problems to the lighting designer. The campus sets out to achieve an outdoor environment that lends itself naturally to student life. It is designed to be at harmony with itself and with the surrounding neighbourhood. That harmony must not be disturbed by the lighting, which must not be too loud and which will be unwelcome if it intrudes on a neighbouring space.

The lighting must also reflect the different purposes of the various spaces on a campus. Some spaces are small and private, others large, public, and unenclosed. The lighting equipment will correspondingly range from small luminaires – possibly built into enclosing walls – to large luminaires on tall poles.

The light source must be selected with care. It must give off light which is compatible with the landscape being illuminated. It is probable that phosphor coated mercury and metal halide lamps provide the best compromise between the need for good colour rendering and the need for lamps of high efficiency.

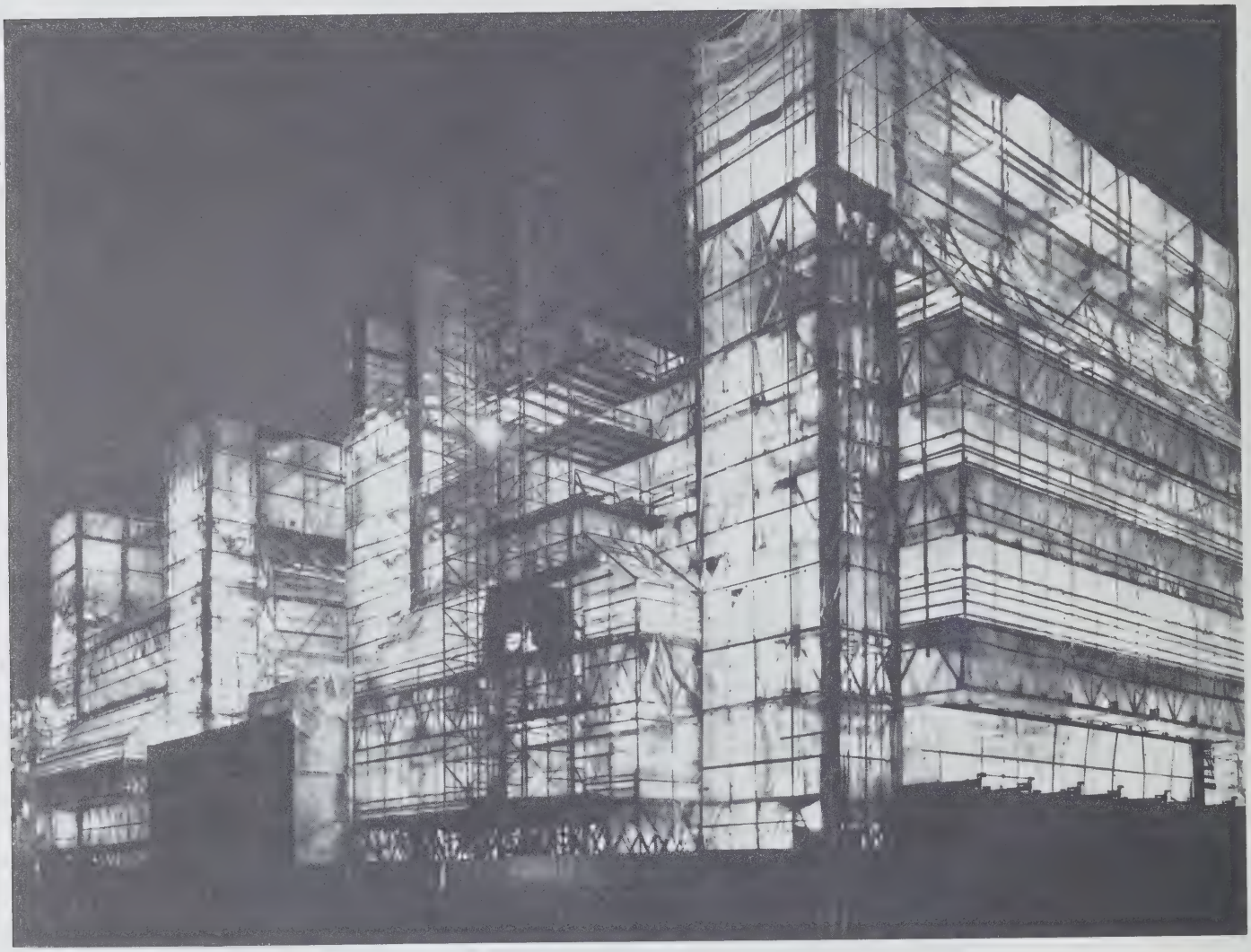
Luminaires used outdoors get dirty quickly. Most luminaires breathe, drawing in dirt-laden air. Also, insects are attracted by the light: a thick layer of dead insects is commonly found inside a luminaire. Consequently, the luminaire should either be tightly gasketed or else completely sealed and fitted with a breather filter.

Plastics, including polycarbonate, have replaced glass bowls and lenses in some outdoor luminaires. Polycarbonate has a high impact strength and, although it discolours somewhat, is frequently selected for luminaires where vandalism might occur.

Fanshawe College, Main Campus, London

Craig Zeidler Strong, Architects

PHOTO: TOM BUCHSLER



McMaster University, Health Sciences Centre, Hamilton

Craig Zeidler Strong, Architects

9. Lighting in The Year 2000

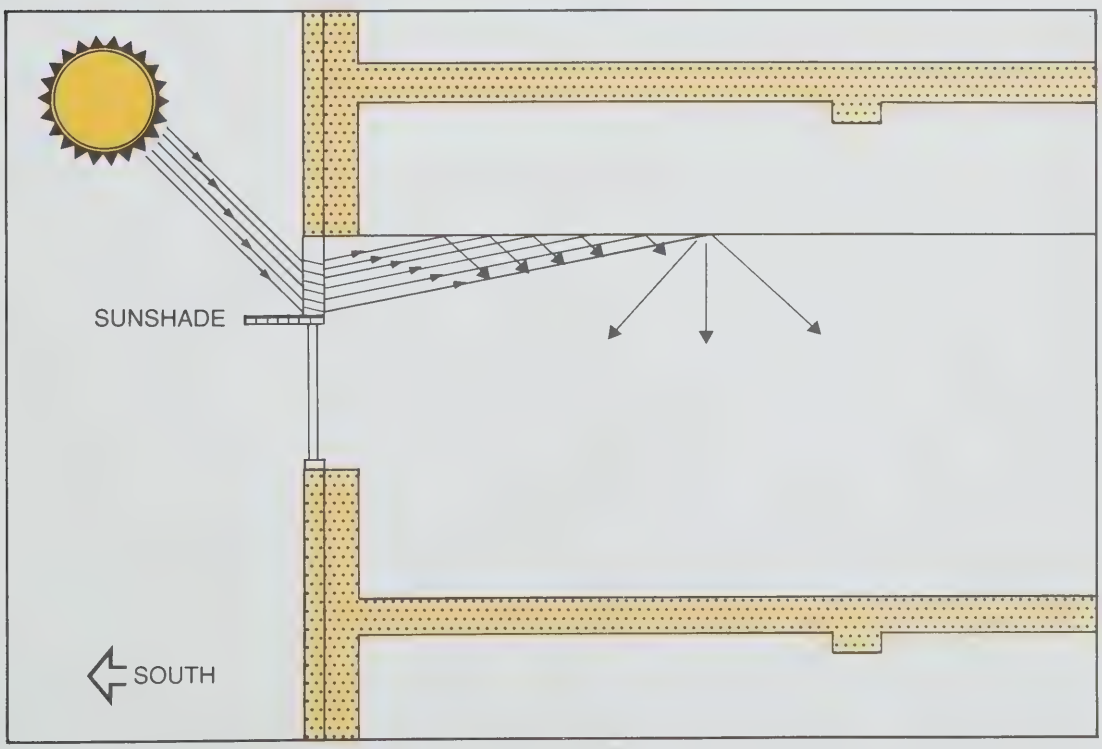
It is anticipated that over the next twenty years lighting research will be aimed at:

- achieving a solid scientific base for illuminance recommendations;
- reducing the electrical energy consumed by lighting systems;
  This will include work on the more effective use of daylight and the development of more efficient lamps of good colour rendering.
- studying the effect of light on health and well-being.

Listed below are a number of specific applications of the above research, together with some other design criteria which are expected to be used in the year 2000.

- All lighting design will be carried out by a lighting specialist who will be skilled in combining daylight and electric light to produce the most effective lighting system. It will have been found that the common present practice of making one specialist responsible for daylighting and another responsible for electric lighting does not result in the best lighting design.
- Sunlight will be collected from outdoors and then distributed throughout a school by "light pipes".
- Beamed sunlight will be used to provide usable illumination in a school. A device such as reflecting venetian blinds will be used to project the sunlight onto the ceiling where it will be diffusely reflected onto the work.
- Guidelines will be developed to optimize the design of windows. These guidelines will take into account psychological considerations such as the response of people to windows of different shapes and sizes, as well as parameters such as latitude, climate, and orientation.
- Glazing will be developed which will respond to changing daylight conditions. For example, the glazing may cloud over and block the hot summer sun, but let the sun's rays pass through during the winter to warm and illuminate the interior space.
- Greenhouses will be built along the walls of a school. They will capture heat from the sun, and this will be used to warm the school. Shutters over the glass will retain the heat at night. The greenhouses will grow food for consumption in the cafeteria.
- The present IES illuminance recommendations, which are based on consensus, will be replaced by recommendations based on scientific study.

Use of Reflecting Blind to Project Sunlight to Interior of Space



- Guidelines will be developed on the effect of light and lighting systems on health and well-being.
- Lamps of good colour rendering and of greater efficacy will be developed. The theoretical maximum efficacy of a white light source is about 300 lm/W. The maximum efficacy of a present-day white light source is about one-quarter of this value: there is a lot of room for improvement.
- HID lamps will be instant starting and of better colour rendering.
- Low wattage HID lamps that do not require a separate ballast will be a direct, high-efficiency replacement for incandescent lamps.
- Lighting systems will be specially designed for use in spaces containing visual teaching aids (such as visual display units).
- Life-cycle costing will be used instead of initial cost in drawing up the budget for school building and operating costs, including the budget for the lighting system.

  Life-cycle costing assesses the economic consequences of various design alternatives as they relate not only to the capital cost but also to the future costs of a lighting system, such as the cost of energy, replacements, and maintenance. This method of costing minimizes the impact of variables which are beyond the control of the lighting designer. One particular variable is the future cost of energy.
- Power load (in kW) will no longer be used as a figure of merit with which to compare the energy-conserving properties of lighting systems. Instead, the comparison will be on the basis of actual energy (in kWh), which will take into account the switching and dimming characteristics of the systems.

  The electrical energy used for lighting is the product of the lighting power load (in kW) and the time (in hours) that load is in use. Thus

  Energy (kWh) = Power (kW) x Time (h)

  At present only the power load is generally considered in designing a lighting system: the smaller that load for a given area and use, the more energy-efficient the system is considered to be. This statement, however, is not accurate, since it does not take into account the number of hours the system will be switched on. Moreover, it does not take into account reductions in the power load resulting from dimming systems coupled to daylight: as daylight increases, the dimming systems will reduce the electric lighting and thus the power drawn by that lighting.
- Panel lamps will be developed which will not have to be directly connected to a source of electrical power.
- The lighting and other requirements for electricity will be met by on-site power generation. When needed, this will be supplemented by power from the local utility. A micro-processor will monitor the system.

Bibliography

(Principal references only)

Aston, S.M., and Bellchambers, H.E. "Illumination, Colour Rendering and Visual Clarity." *Lighting Research and Technology*, vol. 1, no. 4 (1969), pp. 259-61.

Collins, Belinda L. "Review of the Psychological Reaction to Windows." *Lighting Research and Technology*, vol. 8, no. 2 (1976), pp. 80-88.

Illuminating Engineering Society of North America. *IES Lighting Handbook*. 5th and 6th editions. New York: IES, 1972 and 1980.

Mayron, Lewis W., et al. "Light, Radiation and Academic Behavior." *Academic Therapy*, vol. X, no. 1 (Fall 1974), pp. 33-47.

O'Leary, K. Daniel, et al. "Children's Hyperactivity Behavior Under Two Lighting Conditions." In *Proceedings: 5th Annual Meeting, American Society for Photobiology*. New York: ASP, 1977.

Wotton, Ernest. "Some Considerations Affecting the Inclusion of Windows in Office Facades." *Lighting Design and Application*, vol. 6, no. 2 (1976), pp. 32-40.

Glossary

Brightness (also called subjective brightness): A sensation resulting from viewing surfaces or spaces from which light is emitted. Thus, when we say, "The wall is brighter than the ceiling" or "That luminaire is too bright", we are describing our subjective reaction as opposed to a measured quantity.

(Electric) Energy: The unit is the watt-hour or, more often, the kilowatt-hour (kWh). Thus, the daily 24-hour energy consumption by two 500 W lamps is 24 kWh.

(Electric) Power: The unit of power is the watt (W). Thus, when we say that a lamp circuit draws 97 watts, we are referring to the power drawn and not the energy consumed.

Equivalent Sphere Illumination (ESI): A method of specifying illuminance which takes contrast (and hence visibility) into account.

Illuminance (sometimes also referred to as illumination; level of illumination; lighting level): The concentration of luminous flux on a surface.

The unit used in Canada has been the footcandle (fc) which is equivalent to the illuminance of 1 lumen uniformly distributed over a surface area of one square foot.

The SI (or metric) unit is the lux (SI symbol: lx). One lux is the illuminance of 1 lumen uniformly distributed over a surface area of one square metre (1 m^2).

Thus 1 fc = 10.76 lx or 1.076 dalx

Lumen (lm): The unit of luminous flux – the stuff we call light. For example, a new 100 W lamp may emit 1700 lm.

Luminaire: The complete lighting unit consisting of the lamp or lamps, together with the parts designed to distribute the light, to position and protect the lamps, and to connect the lamps to the power supply. Formerly known as "lighting fixture" and in Great Britain "light fitting".

Luminance: The concentration of luminous flux emitted from a luminous or reflecting surface.

The unit used in Canada has been the footlambert (fL) which is equivalent to 1 lumen transmitted through or reflected by one square foot of surface.

The SI unit is the nit (nt) which is equal to 1 candela per square metre (cd/m^2). (The candela [cd] is the SI unit of luminous intensity.)

Thus 1 nt = 3.43 fL

In everyday speech the term "brightness" is used loosely instead of "luminance". Thus, one might say that "the brightness of that wall is 10 cd/m^2" when, to be correct, the term "luminance" should have been used. Luminance is a measured quantity; brightness is not.

Luminous efficacy (or, in short, efficacy): The quotient of the total luminous flux (lumens) emitted by the total lamp power (watts) input. It is expressed in lumens per watt (lm/W).

Thus, if a 100 W lamp emits 1700 lm, its efficacy is 17 lm/W.

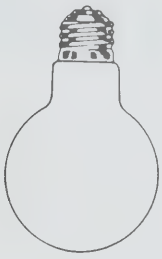
The term "luminous efficiency" has, in the past, been used extensively for this concept.

Reflectance: The ratio of the reflected flux to the incident flux – that is, the percentage of light falling on a surface that is reflected.

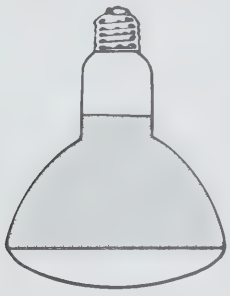
Appendix 1: Principal Lamp Types Used

Incandescent lamps

Lower wattage lamps (usually 150 W or less) most commonly used for general lighting have Type A bulb and, usually, Medium Screw base. (Lamps are also available with Candelabra Screw, Intermediate Screw, and D.C. Bayonet bases.)



Spherical globe-shape lamp with Type G bulb and Medium Screw base.



Reflector lamp with Type R bulb and Medium Screw base. An aluminum coating is vaporized on the inside of the bulb to act as a reflector. Control of the beam spread is determined by the bulb shape and the degree of frosting of the inner bulb surface. Spot lamps are lightly frosted; flood lamps are heavily frosted. These lamps are suitable for indoor use only since the hot bulb will break if rain or snow falls on it.

Reflector lamp with Type PAR bulb and Medium Skirted Screw base. The bulb shape is similar to the R bulb except that it is made of two pieces of pressed glass instead of a single piece of blown glass. A lens system is moulded on the lamp face. The beam control is more accurate than that of an R bulb. The hot bulb will not break if rain or snow falls on it, so the lamp can be used outdoors as well as indoors.

The reflecting surface may be either a standard aluminum coating or a dichroic filter. The latter is a many-layer coating of metallic salts. It reflects light into the beam but allows heat from the lamp to escape through the reflector sides. Thus the radiant heat in the lamp beam is reduced.

A luminaire approved by the Canadian Standards Association for use with a PAR lamp with a standard aluminum reflector may not be approved for use with a PAR lamp of the same voltage with a dichroic filter reflector. A luminaire must be specifically approved for use with the latter lamp.

Reflector lamp with Type ER bulb and Medium Screw base. The bulb is similar to the R bulb but designed to focus the light beam at a spot a few centimetres ahead of the lamp. The lamp works more efficiently than the R lamp in many deep-baffled downlights.

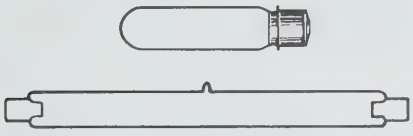
Tubular lamp with Type T bulb. The lamps come with a variety of types of bases including Medium Screw, Intermediate Screw, Candelabra Screw, D.C. Bayonet, and Disc.

Higher wattage lamps (usually of more than 150 W) most commonly used for general lighting have Type PS bulb. Up to and including the 300 W size, most lamps have the Medium Screw base; the Mogul Screw base is used on most higher wattage lamps.

High Intensity Discharge (HID) lamps

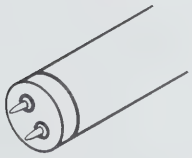
Most mercury and metal halide lamps of 400 W or less and high pressure sodium lamps of 1000 W or less have the Type E bulb. In the smaller diameter lamps (E18, for example) the bulge in the bulb is much less pronounced than that illustrated here. Low wattage lamps have the Medium Screw base; medium and high wattage lamps have the Mogul Screw base.

Most mercury and metal halide lamps of more than 400 W have the Type BT bulb and the Mogul Screw base.

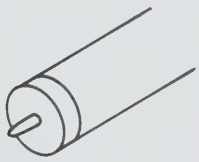


Low pressure sodium lamps have the tubular Type T bulb. Usually the lamp has either a single Bayonet base or else a Bi-pin base at each end.

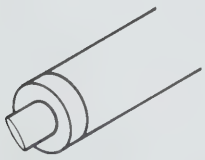
Fluorescent lamps



Rapid Start lamps (such as the common 4-foot 40 W lamp) and some Instant Start lamps have the Medium Bi-pin base.



Most Slimline (Instant Start) lamps have the Single Pin base.



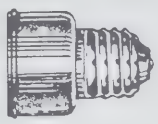
800mA., 1000mA., and 1500mA lamps have the Recessed Double Contact base.

Notes:

1. The maximum bulb diameter in eighths of an inch is given in the lamp description appearing in the manufacturers' catalogues. For example, the standard 4-foot 40 W fluorescent lamp has a T12 bulb – a tubular bulb twelve-eighths of an inch, or 1½ inches, in diameter.

2. Most lamp bulbs are of common lime glass. However, low expansion "hard" glass, similar to that used to make oven-ware, is used where the lamp may be subjected to thermal shock. A typical lamp with a "hard" glass bulb is the 150 W PAR38 reflector lamp. It can be used out of doors where it is liable to thermal shock from rain and snow.

Typical lamp bases for incandescent and HID lamps (excluding low pressure sodium lamps)

	Principal uses
	Low wattage HID lamps and most general purpose incandescent lamps up to and including the 300 W size. *Medium Screw 1 1/16 in. diameter (d)**
	Medium and high wattage HID lamps and most general purpose incandescent lamps of more than 300 W. *Mogul Screw 1 19/32 in. d*
	PAR reflector lamps. *Medium Skirted Screw 1 1/16 in. d*
	Low wattage incandescent lamps of types not used for general lighting purposes (such as some tubular lamps). *Intermediate Screw 5/8 in. d*
	Candelabra Screw 1/2 in. d
	Bayonet 5/8 in. d
	Disc 7/8 in. d

Note:
For many years brass was almost the only material used for screw lamp bases. Now, however, most incandescent lamps up to and including the 300 W size, and some other lamps, have aluminum bases. Aluminum costs less than brass, it is easier to work, and it is a better conductor of electricity. Screw bases of brass are still recommended for damp locations: in these locations the aluminum base may bind with the lampholder making it difficult to remove the lamp.

*The production of lamp bases in metric units is not yet scheduled by the manufacturers.

Appendix 2: The Effects of Ultraviolet Radiation

The following is a statement by the (British) Chartered Institution of Building Services (CIBS) Lighting Division:

. . . considerable publicity has been given to the claim that exposure to light from conventional fluorescent lighting can have deleterious effects on people's health, strength and well-being. Further, it has been asserted that one particular light source, called a "full-spectrum" fluorescent lamp can alleviate these problems. The purpose of this statement is to set down the opinion of the CIBS Lighting Division Technical Committee on these claims.

The first point to note about these claims is that they do not refer to the ability to see. What is being claimed is that in some unspecified way radiation from conventional fluorescent lamps can have general, non-visual effects. This is not an unreasonable proposition given that some non-visual effects of light are well established. For example, human circadian rhythms are known to be linked to the naturally occurring day-night cycle. The second point to be noted about these claims is that they identify the factor responsible for the effect, namely the relative lack of near ultra-violet radiation in the spectral emission of conventional fluorescent light sources. The full-spectrum fluorescent lamp emits much more near ultra-violet radiation than most conventional fluorescent lamps and in this respect is much more like daylight outdoors.

The validity of these claims can be considered at two levels: first the level of practical experience, second the level of scientific experiment. At the level of practical experience it is important to realise that it is not just fluorescent lamps which have relatively little near ultra-violet emission. All light sources used for conventional interior lighting, eg. incandescent lamps, fluorescent lamps, high pressure discharge lamps, and daylight admitted through windows, have a reduced near ultra-violet component compared with that available outdoors. Yet all these light sources have been used for many years for interior lighting. In this situation it does not seem unreasonable to expect that if the claims for near ultra-violet were true large differences in the health, strength and well-being of those who work indoors and outdoors would be apparent. No such differences are apparent. This may be because, for most people, exposure to interior lighting occurs for only part of the day. At other times people are exposed to unfiltered daylight and hence to high levels of near ultra-violet radiation. It may be that when people have no access to unfiltered daylight for very long periods, as for example when working for long hours indoors during winter in northern latitudes, then exposure to near ultra-violet radiation from light sources might be beneficial. However, such restricted exposure is rare. For the more usual situation many years of experience with a wide range of different light sources, including daylight, in interiors does not suggest that an absence of near ultra-violet radiation is detrimental to people's health, strength and well-being.

As for the level of scientific experiment, here the picture is more confused. Numerous experiments have been reported dealing with the effect of near ultra-violet radiation on people, animals and plants. Many of these experiments have been poorly designed and inadequately reported. Where clear effects have been found the direction of the effect has sometimes been different for different creatures. Frequently the assumption has been made that the results from animals and plants are applicable to people but only rarely has the influence of intervening variables been considered. Overall, there is no consistent pattern of results which indicates a clear beneficial effect of near ultra-violet radiation on people's health, strength and well-being.

Nonetheless, there are enough data to suggest that the spectrum of radiation to which people are exposed might be important in more ways than simply allowing for vision to occur, but at the moment the case is not proven. What is required now is carefully conducted research which seeks to identify the effects of different forms of radiation on people under realistic conditions. Results from such research would be more convincing than sensational assertions based on anything from the behaviour of hyperactive children through tooth decay in hamsters to the feeding habits of snakes. Until more reliable evidence is available, the scientific status of the claims about the benefit of near ultra-violet radiation from light sources must remain in doubt.

Building Services, vol. 3, no. 3 (1981), pp. 36–37.

The following statement has been made by the Ontario Ministry of Health:

The quantities of ultraviolet radiation available from artificial sources are found to be very low. Eight hours exposure to 500 foot-candles is the approximate equivalent of fifteen minutes spent outdoors on a sunny day. Consequently, the use of artificial illumination sources which simulate the solar spectrum will be of very limited use until such time sufficiently documented scientific evidence proves otherwise.

Illumination Systems in Hospitals, Ministry of Health, Ontario, 1979, p. 5.1.